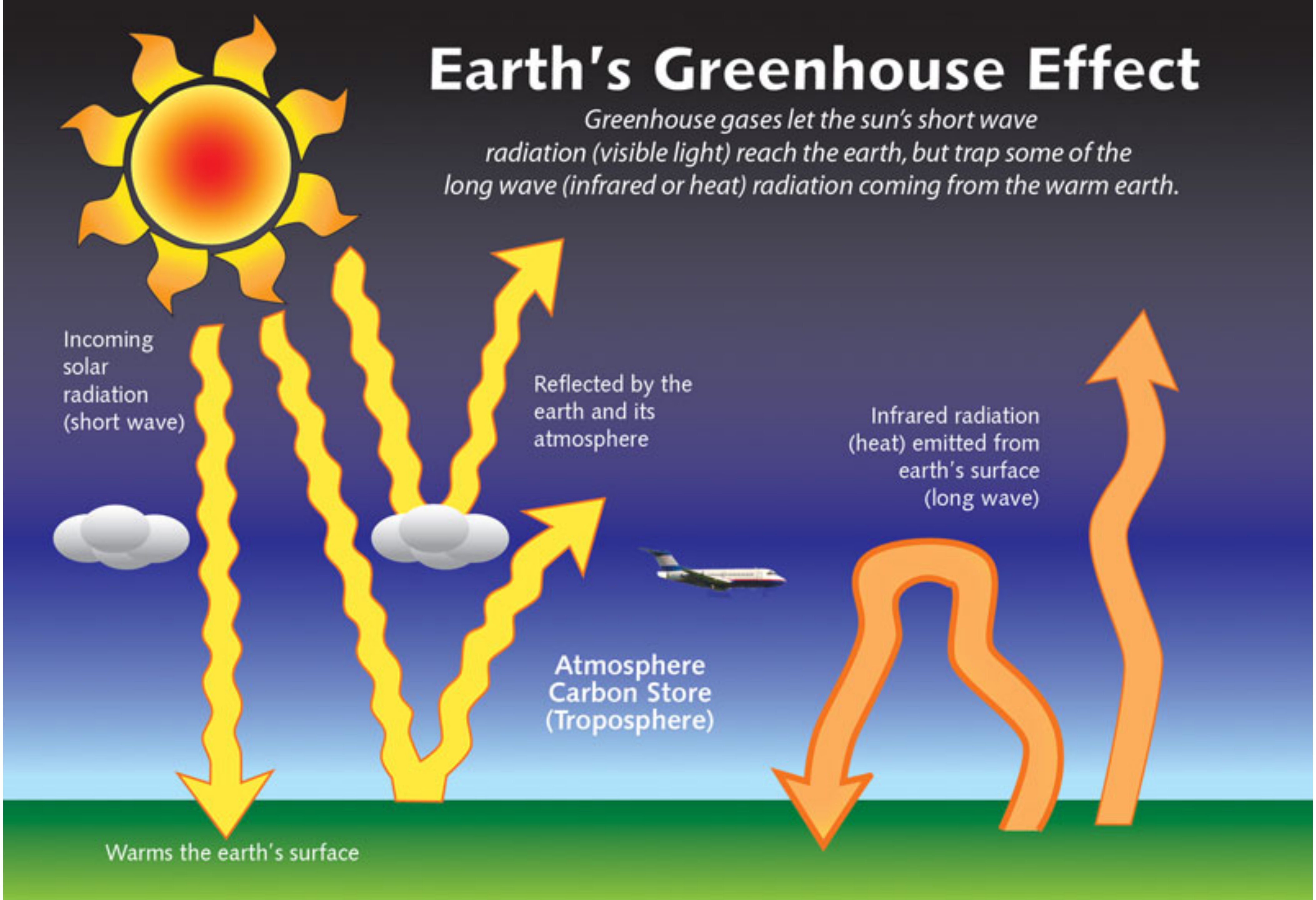
The Peculiar Negative Greenhouse Effect

Sergio A. Sejas, Patrick C. Taylor, and Ming Cai

CERES Science Team Meeting

NASA Langley Research Center

May 16, 2018


Earth's Greenhouse Effect
Greenhouse gases let the sun's short wave radiation (visible light) reach the earth, but trap some of the long wave (infrared or heat) radiation coming from the warm earth.
Incoming solar radiation (short wave)
Reflected by the earth and its atmosphere
Infrared radiation (heat) emitted from earth's surface (long wave)
Atmosphere Carbon Store (Troposphere)
Warms the earth's surface

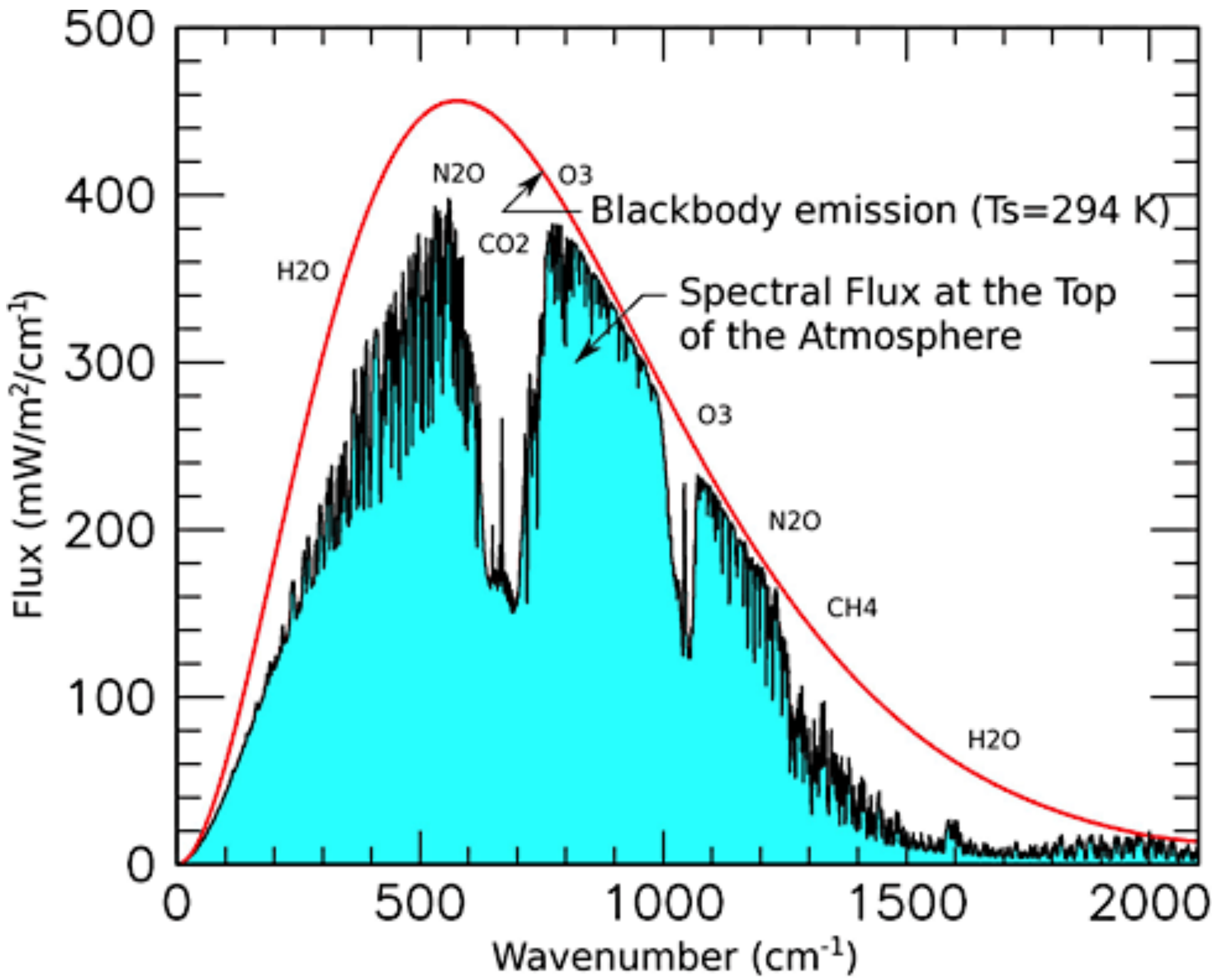
Greenhouse Effect Quantification

- Greenhouse gas absorption reduces the amount of longwave (LW) energy escaping to space, such that the top-of-atmosphere (TOA) outgoing LW radiative (OLR) flux is less than the surface LW emission (i.e., a warming effect).

Greenhouse Effect (GHE) Strength

$GHE = LW_{sfc}\uparrow - OLR$

[Raval and Ramanathan, 1989].



Negative GHE?

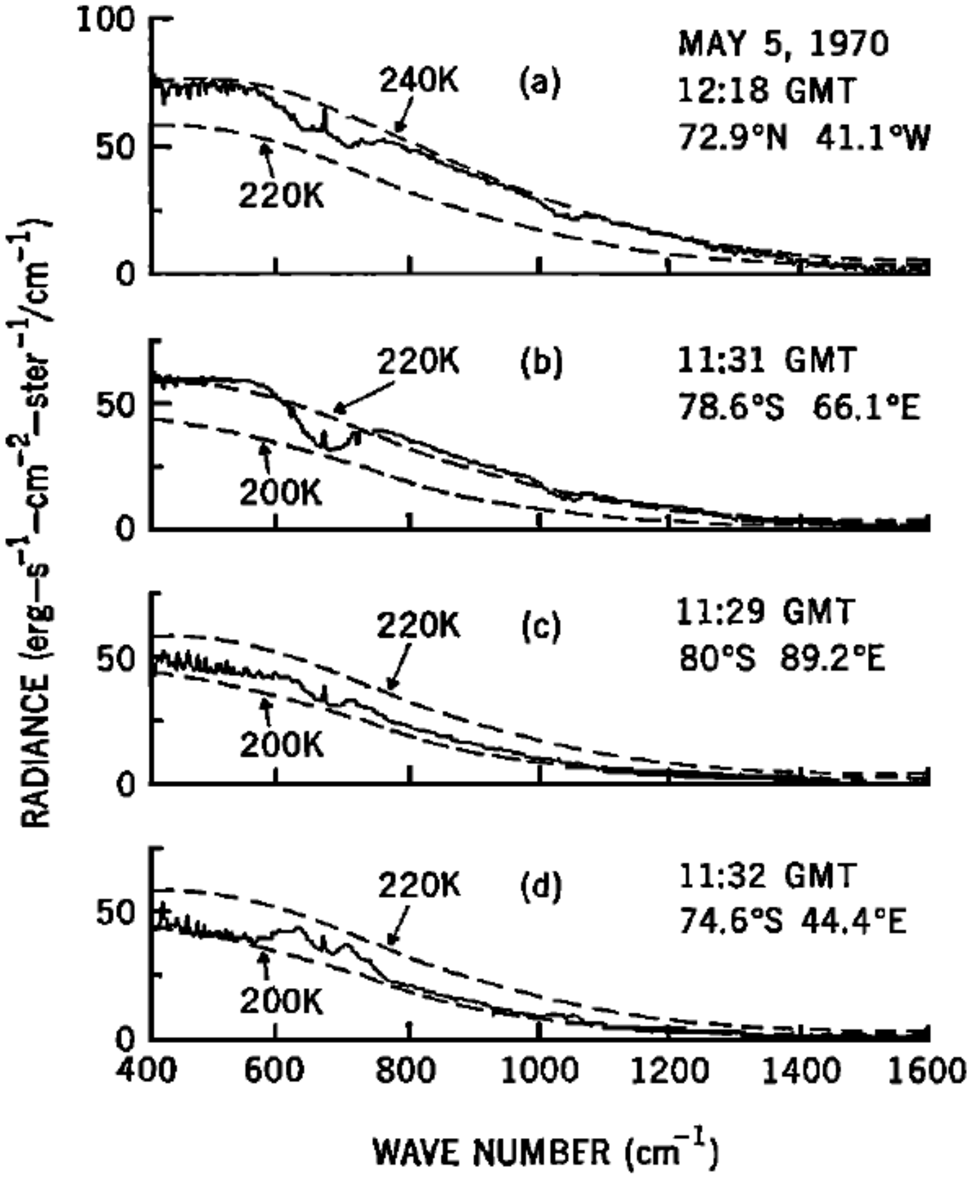
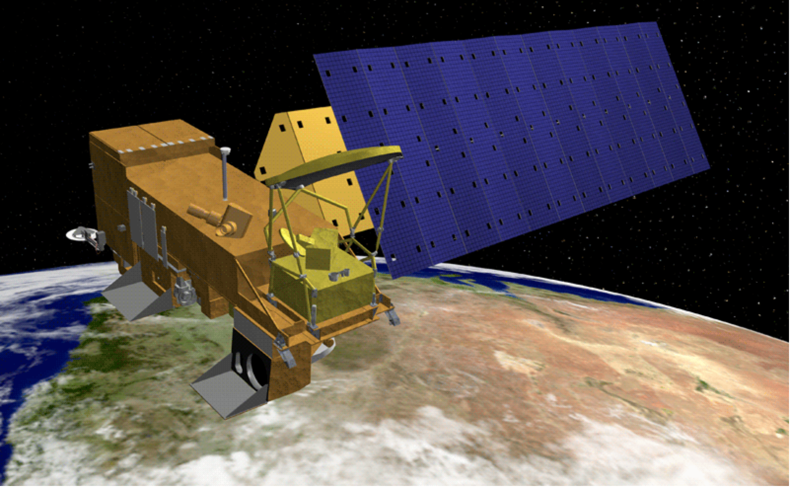


Fig. 12. Examples of polar spectra. The spectrum in *a* was obtained over Greenland; the spectra in *b*, *c*, and *d* were obtained over Antarctica.

Hanel et al. (1972)

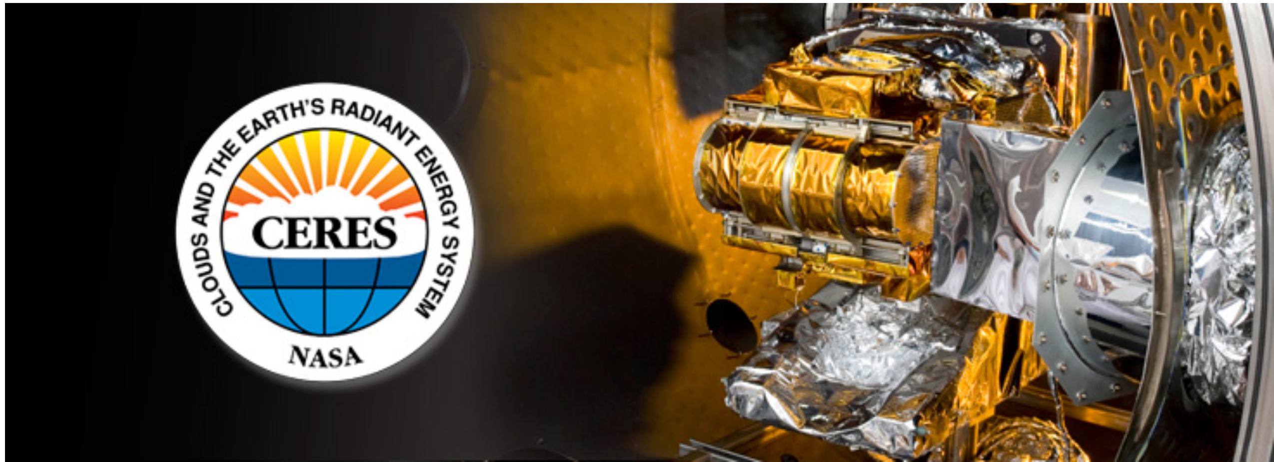
Nimbus 4 measurements

- Schmithusen et al., 2015 found a robust negative GHE over the Antarctic Plateau. Attributed it to stratospheric CO_2 and warmer stratospheric temperatures relative to the surface.



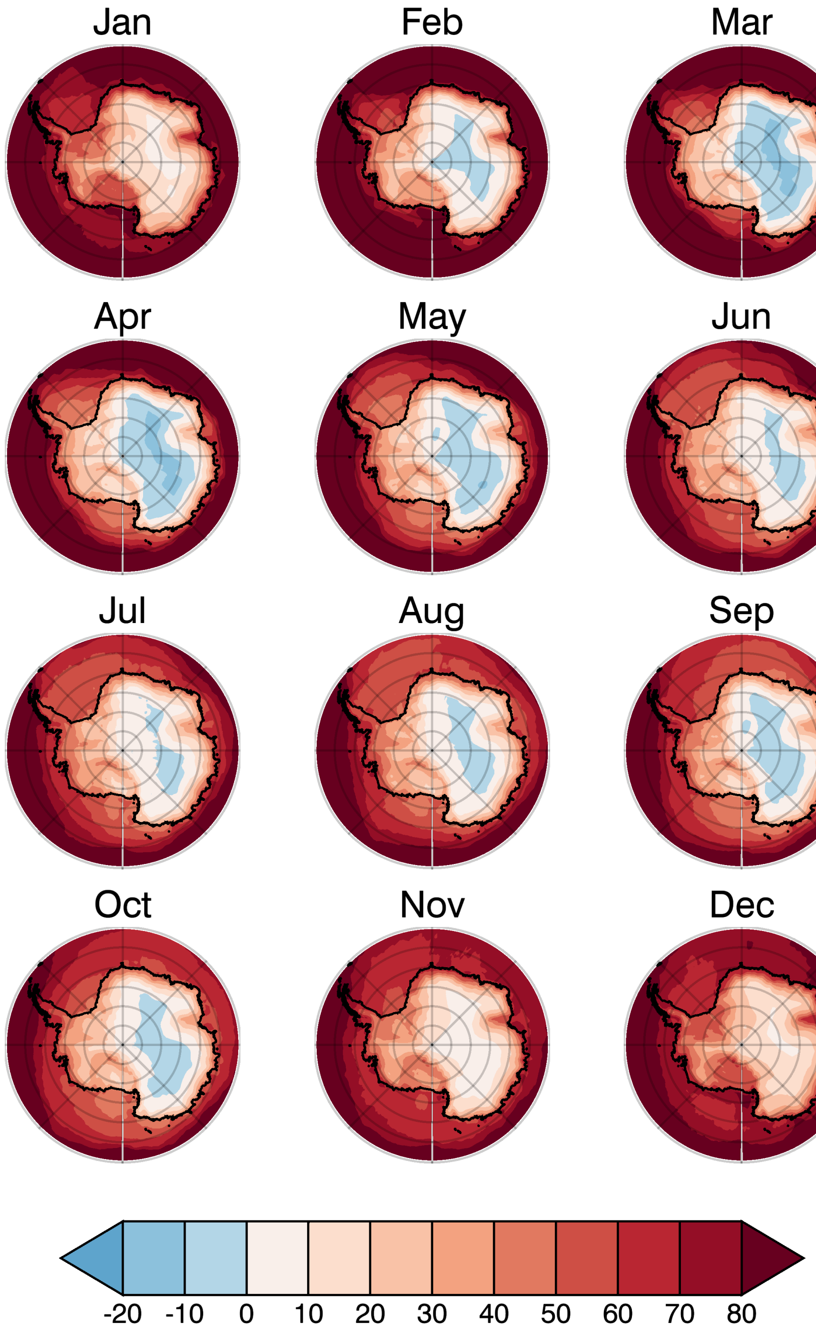
Data

- AIRS and CERES EBAF data sets from 2003-2015 were used to estimate the climatological monthly mean broadband GHE over Antarctica.
- The spectral GHE was estimated with the LBLRTM using the AIRS temperature, moisture, and greenhouse gas concentration data as input.

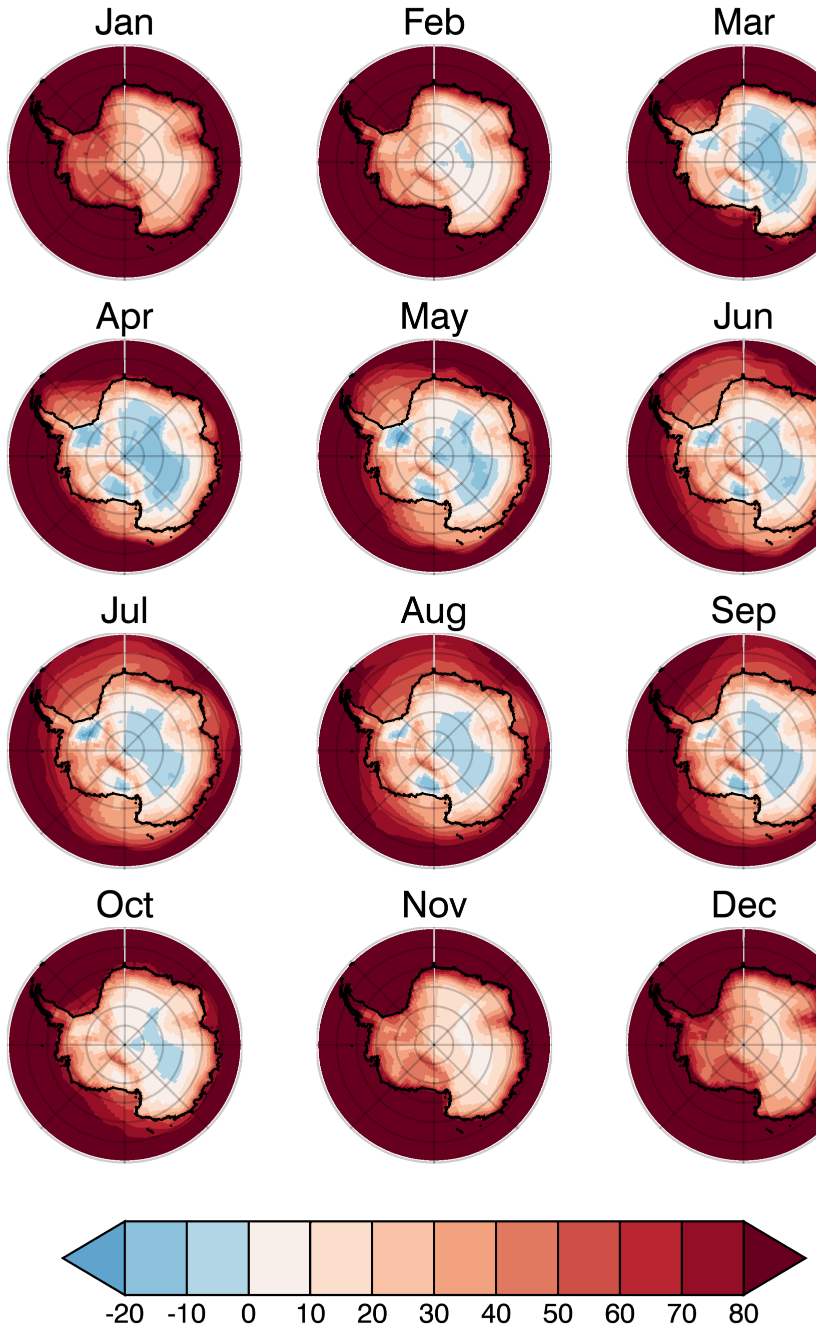


GHE

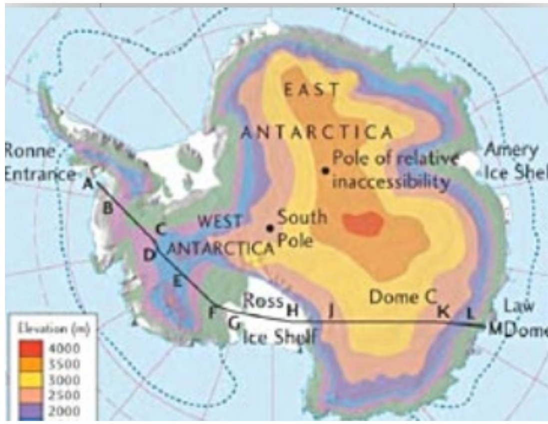
AIRS GHE



CERES GHE



Units: $W*m^{-2}$



GHE = LWsfc↑ - OLR

Spectral GHE

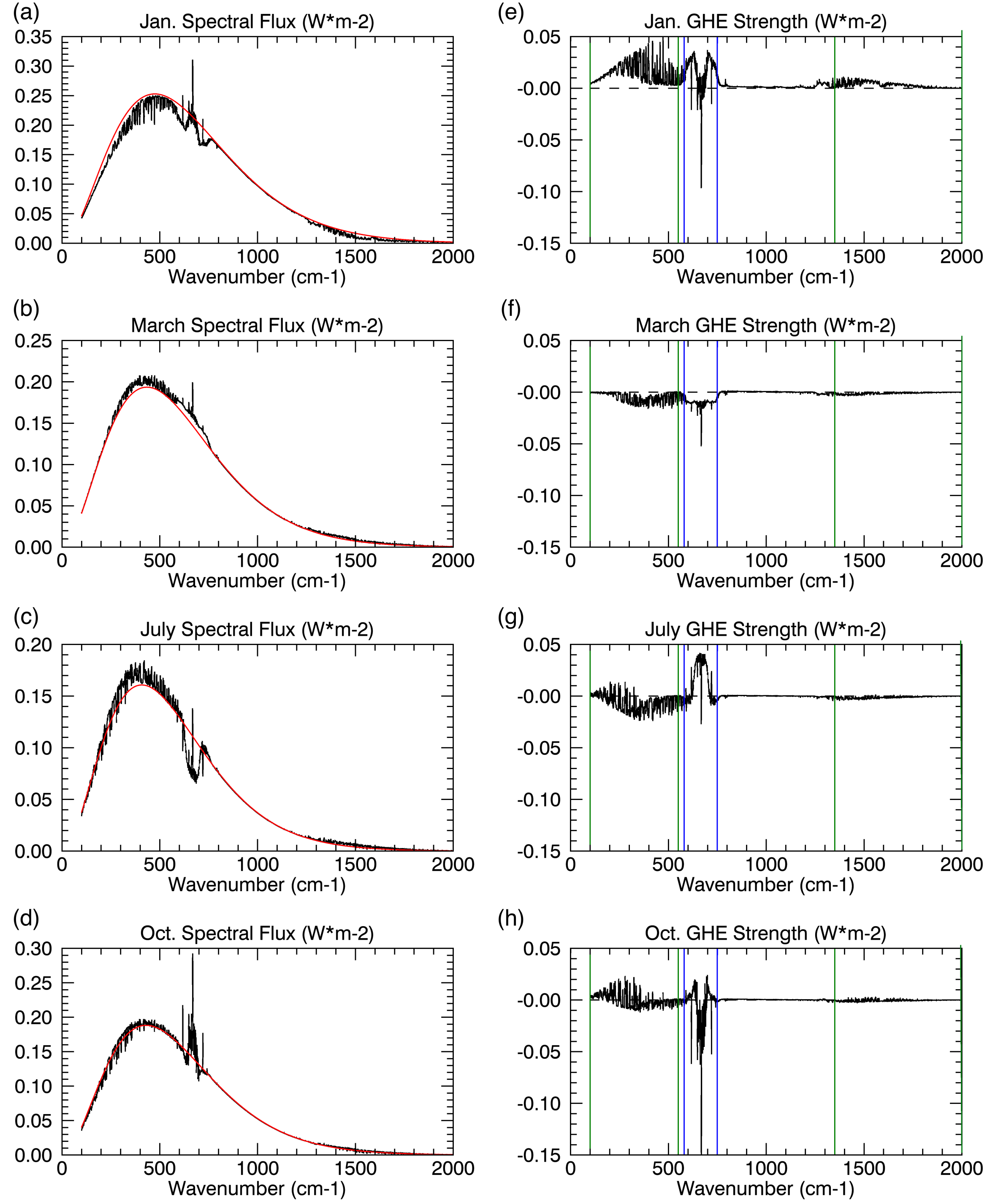


Table 1. Monthly net GHE strength in water vapor bands, CO_2 band, and total LW band.

Month	Water Vapor GHE ($W*m^{-2}$) 100-550 cm^{-1} and 1350-2000 cm^{-1} Bands	CO_2 GHE ($W*m^{-2}$) 580-750 cm^{-1} Band	Total GHE ($W*m^{-2}$) 100-2000 cm^{-1} Band
January	8.32	2.71	12.31
February	0.81	-1.56	-0.45
March	-2.87	-1.85	-4.83
April	-4.03	-0.33	-4.54
May	-3.62	1.29	-2.45
June	-3.68	2.09	-1.69
July	-3.44	2.14	-1.37
August	-3.20	1.89	-1.35
September	-2.54	0.84	-1.69
October	-0.31	-1.08	-1.21
November	5.23	1.65	6.88
December	8.37	3.38	13.15

Radiative Saturation-Level Concept
(Sejas et al. 2016)

- The radiative saturation-level concept is used to explain and understand the vertical variation of the upward or downward monochromatic LW fluxes and classifies the upward monochromatic LW flux at a specific height into one of three saturation levels:
  - **Undersaturated (LW flux < Blackbody flux)**
  - **Saturated (LW flux = Blackbody flux)**
  - **Oversaturated (LW flux > Blackbody flux)**
- Analogous to Clausius-Clapeyron in the water vapor saturation concept, the blackbody flux is only dependent on temperature and establishes the radiative saturation point.
- The vertical profile of the blackbody flux establishes the saturation line.

Radiative Saturation-Level Concept

(Sejas et al. 2016)

- As the monochromatic LW flux traverses any medium (e.g., the atmosphere) with absorbers (e.g., greenhouse gases) it will tend towards saturation.

$$\pi B_\nu(z) - F_\nu^{\uparrow}(z) = -\pi[B_\nu^*(0) - B_\nu(0)]T_\nu^f(0,z) + \int_0^z \frac{\partial \pi B_\nu(z')}{\partial z'} T_\nu^f(z',z)dz' \qquad (1)$$

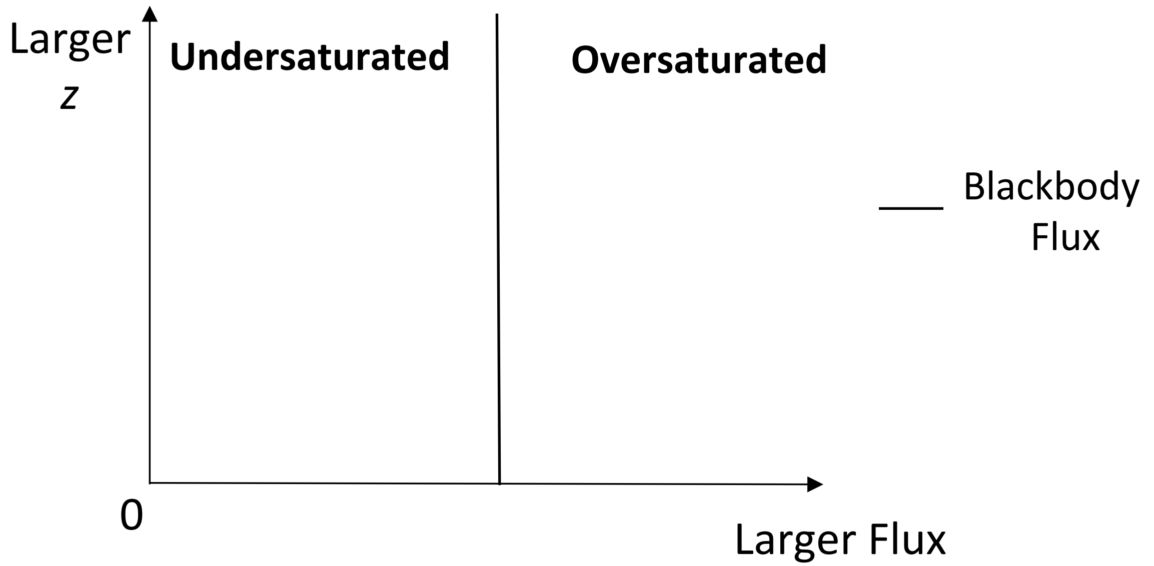
Radiative Saturation-Level Concept

(Sejas et al. 2016)

- As the monochromatic LW flux traverses any medium (e.g., the atmosphere) with absorbers (e.g., greenhouse gases) it will tend towards saturation.

$$\pi B_\nu(z) - F_\nu^{\uparrow}(z) = -\pi[B_\nu^*(0) - B_\nu(0)]T_\nu^f(0,z) + \int_0^z \cancelto{0}{\frac{\partial \pi B_\nu(z')}{\partial z'}} T_\nu^f(z',z)dz' \qquad (1)$$

(assuming a constant vertical temperature profile)



Radiative Saturation-Level Concept

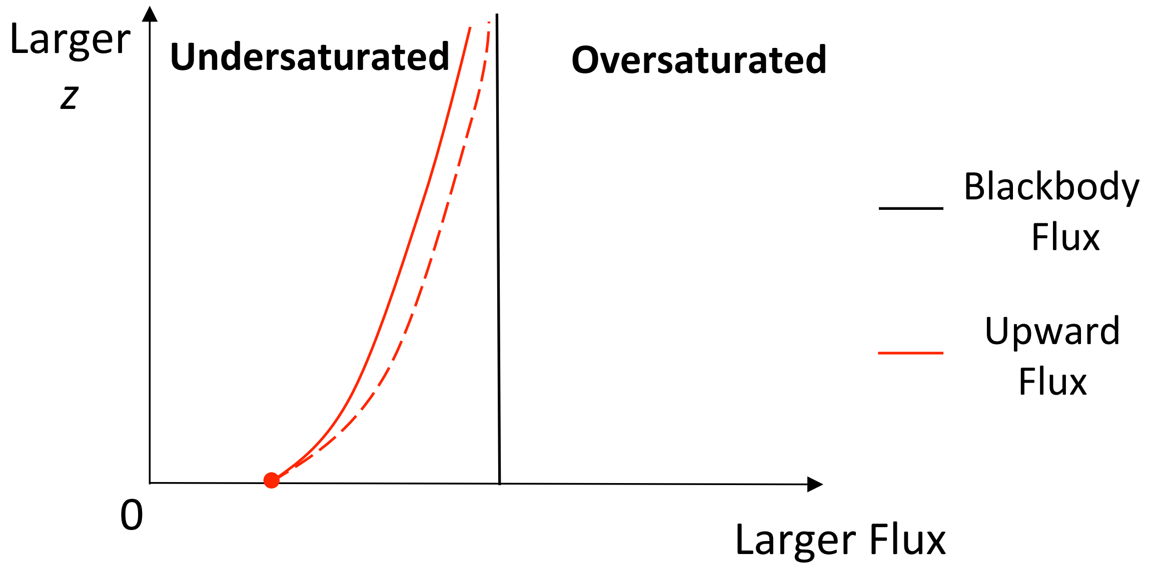
(Sejas et al. 2016)

- As the monochromatic LW flux traverses any medium (e.g., the atmosphere) with absorbers (e.g., greenhouse gases) it will tend towards saturation.

$$\pi B_\nu(z) - F_\nu^{\uparrow}(z) = -\pi[B_\nu^*(0) - B_\nu(0)]T_\nu^f(0,z) + \int_0^z \cancelto{0}{\frac{\partial \pi B_\nu(z')}{\partial z'}} T_\nu^f(z',z)dz' \qquad (1)$$

If undersaturated the upward flux will increase with height, the greater the optical depth the greater the increase.

(assuming a constant vertical temperature profile)



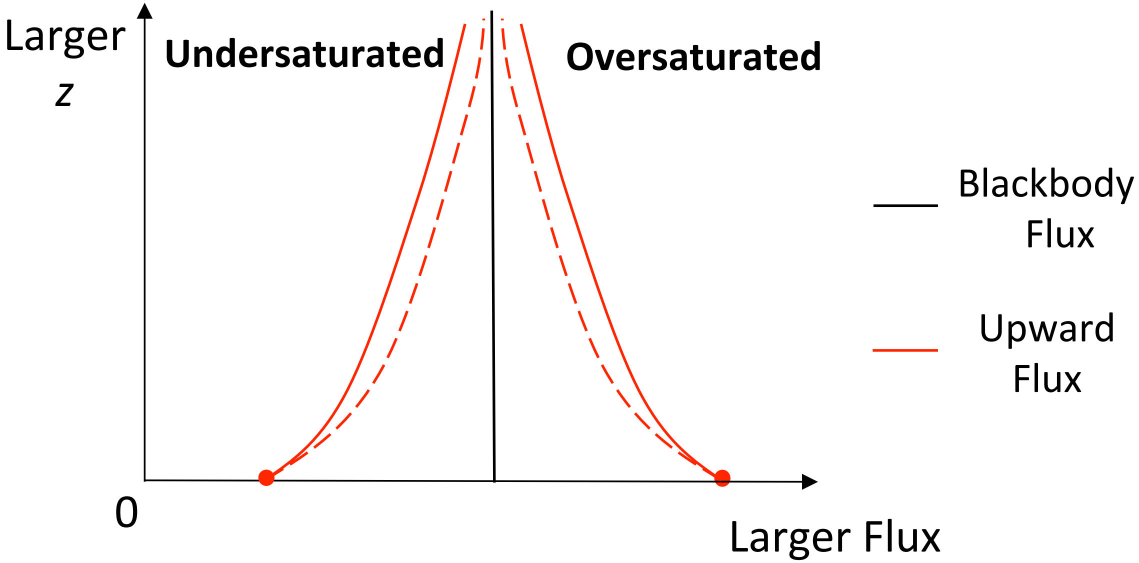
Radiative Saturation-Level Concept

(Sejas et al. 2016)

- As the monochromatic LW flux traverses any medium (e.g., the atmosphere) with absorbers (e.g., greenhouse gases) it will tend towards saturation.

$$\pi B_\nu(z) - F_\nu^{\uparrow}(z) = -\pi[B_\nu^*(0) - B_\nu(0)]T_\nu^f(0,z) + \int_0^z \cancel{\frac{\partial \pi B_\nu(z')}{\partial z'}}^{\,0} T_\nu^f(z',z)dz' \quad (1)$$

(assuming a constant vertical temperature profile)



If oversaturated the upward flux will decrease with height, the greater the optical depth the greater the decrease.

Radiative Saturation-Level Concept

(Sejas et al. 2016)

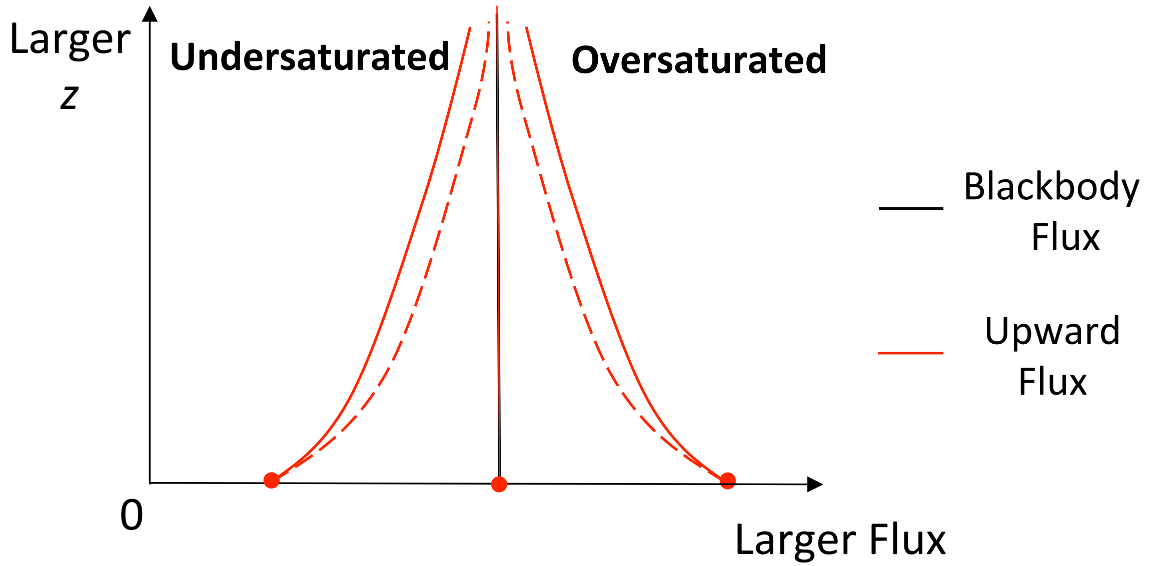
- As the monochromatic LW flux traverses any medium (e.g., the atmosphere) with absorbers (e.g., greenhouse gases) it will tend towards saturation.

$$\pi B_\nu(z) - F_\nu^{\uparrow}(z) = -\pi[B_\nu^*(0) - B_\nu(0)]T_\nu^f(0,z) + \int_0^z \cancelto{0}{\frac{\partial \pi B_\nu(z')}{\partial z'}} T_\nu^f(z',z)dz' \qquad (1)$$

If saturated the upward flux will remain constant, irrespective of the optical depth.

If there are no absorbers the flux will remain constant, irrespective of saturation level.

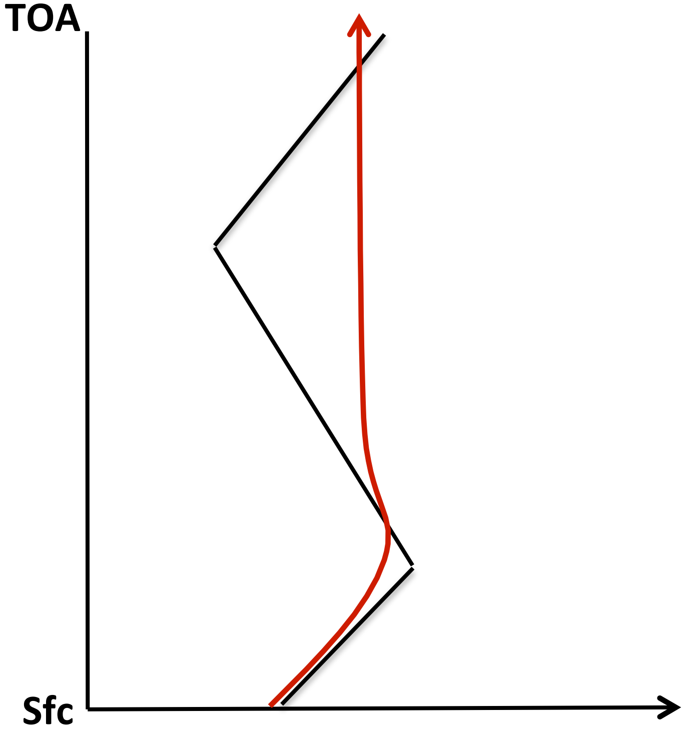
(assuming a constant vertical temperature profile)

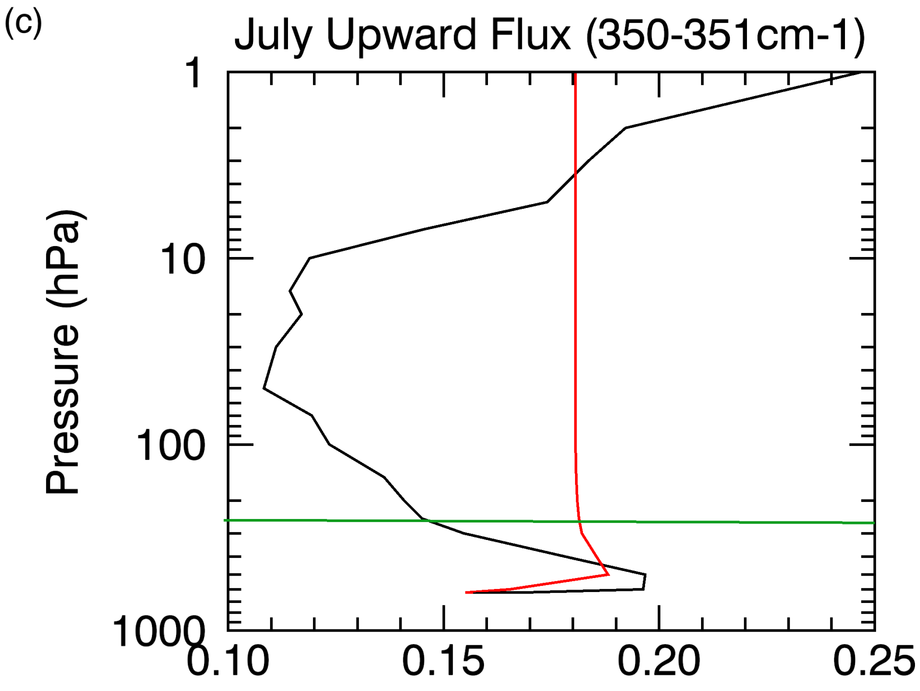


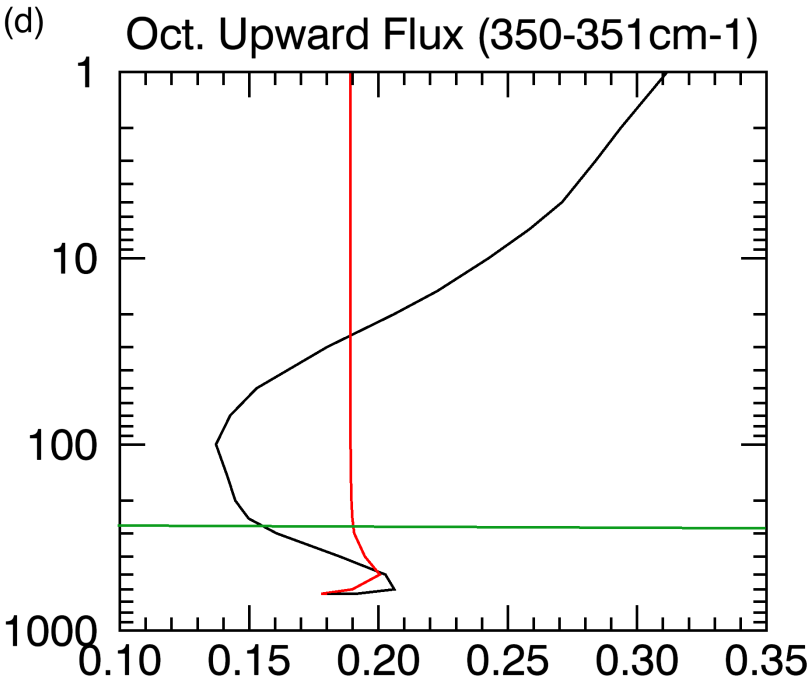
Negative GHE in H_2O Band

Legend: —— BB Flux (Temperature Profile)

—— Upward Flux



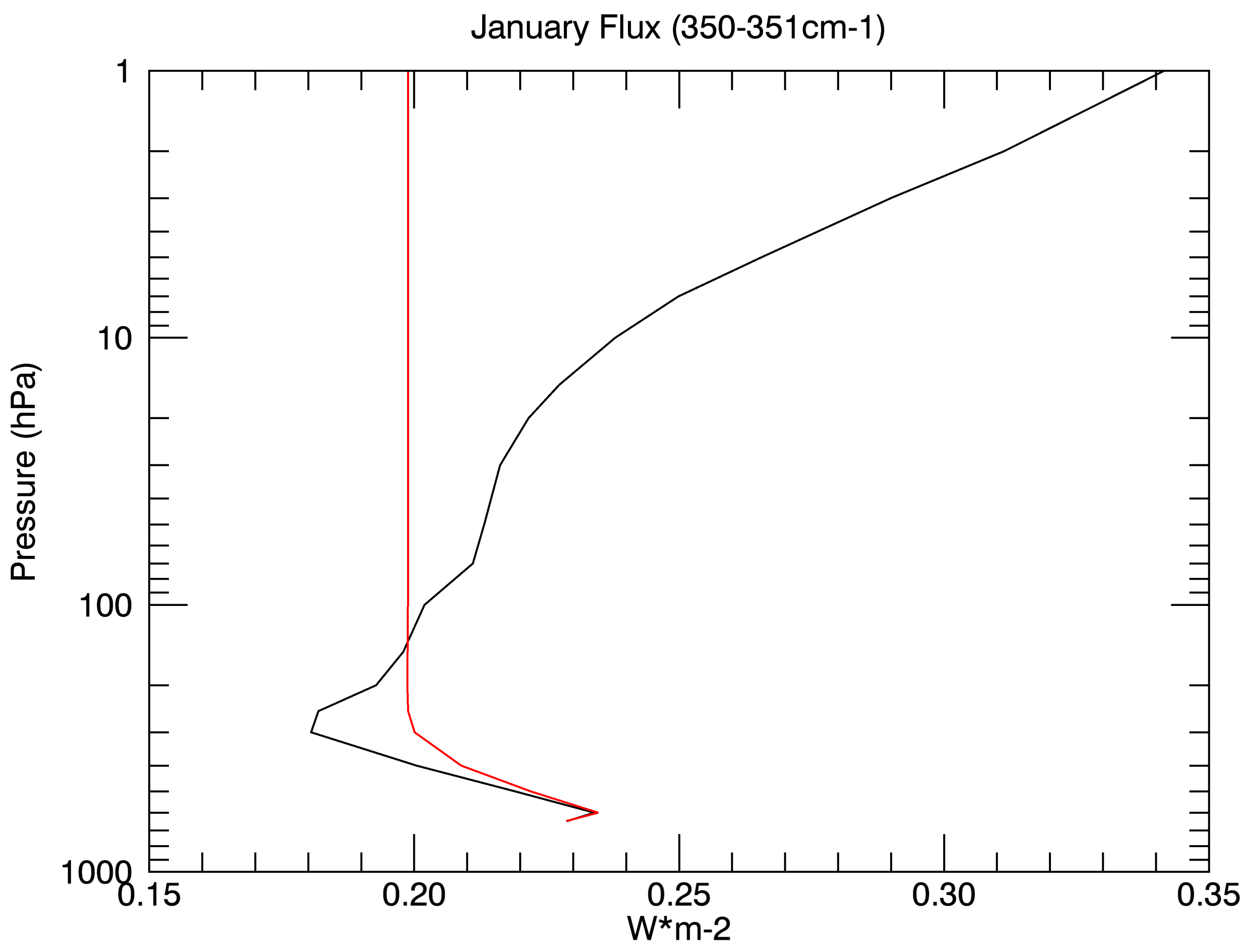




Positive GHE in H_2O Band
(Summer)

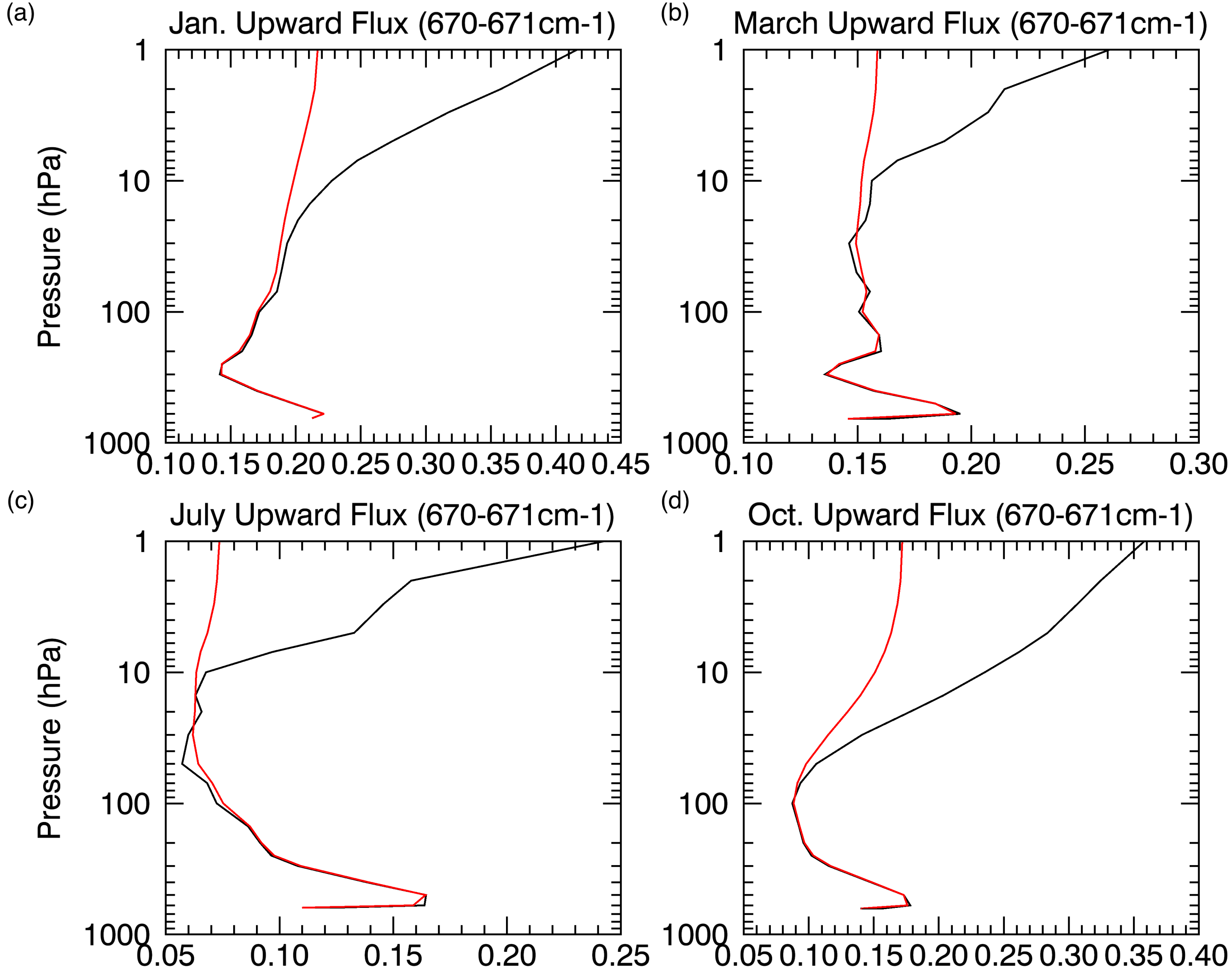
Legend: —— BB Flux (Temperature Profile)

—— Upward Flux



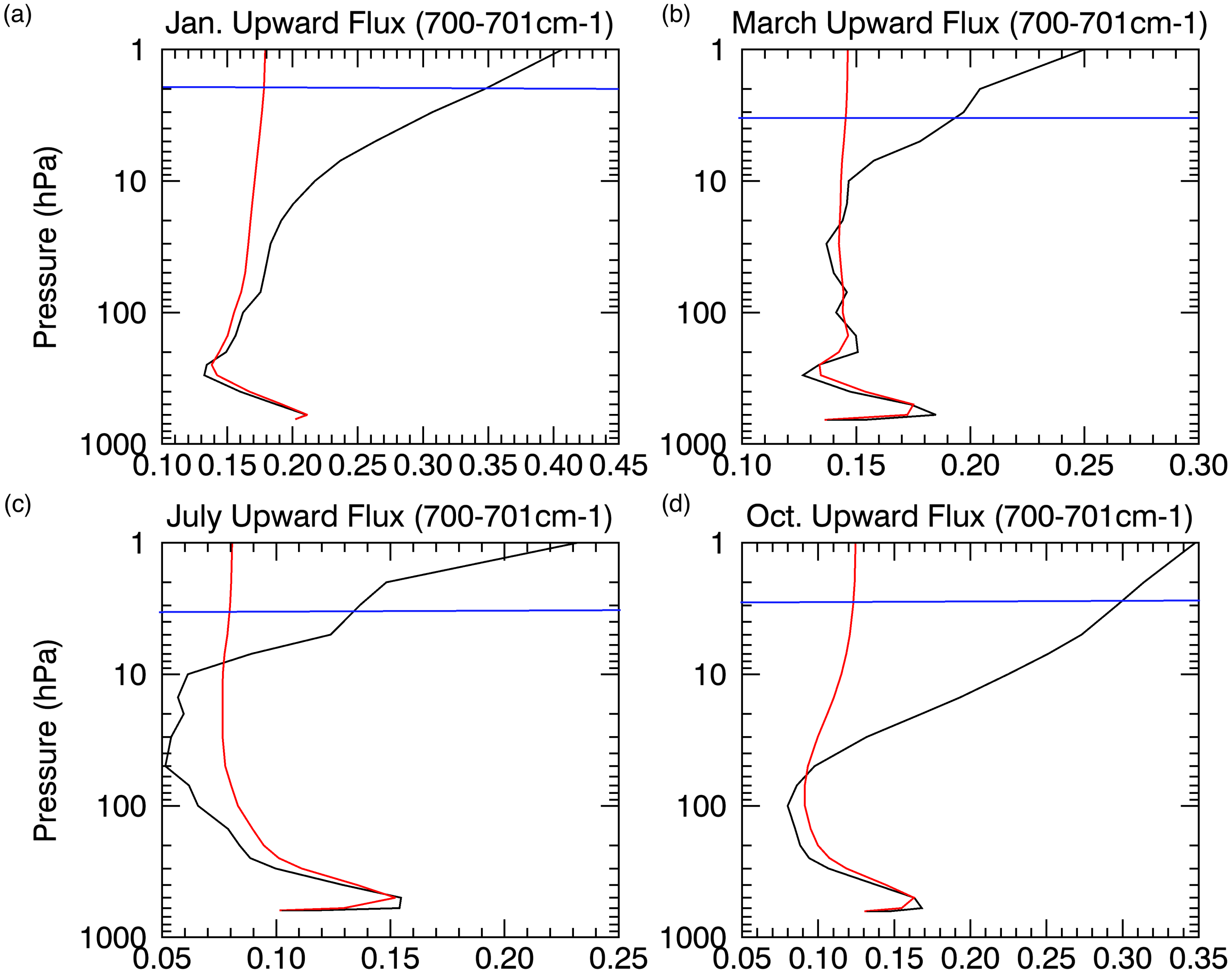
GHE in Inner Core of CO_2 Band

Legend: BB Flux (Temperature Profile) — black line; Upward Flux — red line



GHE in Outer Portion of CO_2 Band

Legend:	black line	BB Flux (Temperature Profile)
	red line	Upward Flux



Key Points

- For a negative GHE to occur temperature must increase with height, driving the saturation flux value above the surface emission.
    - Condition satisfied by the strong surface-based temperature inversion and warmer stratospheric temperatures relative to the surface over the Antarctic Plateau.
    - Necessary but insufficient condition, as optical depth determines how efficiently the upward flux moves toward saturation and a negative temperature gradient can cause the upward flux to decrease below the surface emission.
- *Both* water vapor and CO_2 absorption bands cause a negative GHE, with water vapor playing the primary role!
- The strong surface-based temperature inversion in combination with the extremely dry conditions, particularly above the inversion, lead to a negative GHE for water vapor.

Key Points

- Thus it is the unique climatological conditions over the Antarctic Plateau that cause a negative GHE.
- Over most of the globe the GHE is positive. The results here are thus not contradictory to the well-established and long held view that greenhouse gases warm the planet.
    - Strong surface-based temperature inversions and warmer stratospheric temperatures relative to the surface are rare.
    - Even if strong surface-based temperature inversions occur elsewhere, free tropospheric water vapor is more abundant over the inversions relative to the Antarctic Plateau.

Sejas, S.A., P.C. Taylor, and M. Cai, 2018. Unmasking the Negative Greenhouse Effect. Accepted in NPJ Climate and Atmospheric Science.